Pre-Quaternary paleotopography reconstruction in the Ordos platform and its integration in the loess landform evolution modeling

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Abstract—**The information underlying the earth surface is the indicator of the environment of the past. Especially the pre-Quaternary underlying terrain of the Ordos platform in the Loess Plateau of China, a base level of soil erosion process and a start geologic node of loess deposition process during the landscape evolution process, which acted as the erosion base to control the development and evolution of the loess landform. In this study, on a basis of multi-source information including detail geologic information, several drillings, RS images and DEMs, we used GIS spatial analysis methods to virtualize and reconstruct a digital elevation model of a pre-quaternary paleotopographic surface in a severe soil erosion area of the Loess Plateau. Then, several indicators are used to quantitatively express the controlling effect of the underlying terrain to the modern terrain. Finally, we used the underlying terrain as the initial topography, employed a landscape evolution model to virtualize the process of the loess landscape formation process. The result shows, the usage of geologic information, together with the GIS spatial analysis method, could help the Geomorphometry in the virtualization of the paleotopography as well as the past environment. A relatively strong landform inheritance relationship could be found according to the significant linear positive correlation between both terrains. The Quaternary loess-deposition process exhibited an apparent accumulation in the windward direction, which supported the hypothesis of an eolian origin for loess in China. With the initial topography and landscape evolution model, we virtualize the evolution process of loess landform. Our results deepen the understandings of the paleotopography and the past environment of the Ordos platform in the Loess Plateau of China, as well as boarding the theory and method in Geomorphometry.**

I. INTRODUCTION

Dynamic phenomenon simulation has been regarded as one of the most important aspect in the environment revealing, explaining and predicting of past, now and future correspondingly towards the research of Virtual Geographic Environment (Lin et al., 2013; Li and Liu, 2006; Cao et al., 2013; Yang et al., 2013). Surface landform evolution process investigating, revealing, modelling, and further simulating have been got increasingly attention in quantitatively expressing the geomorphological process.

The Loess Plateau of China is known for its unique landforms, formed after more than two million years of loess deposition and sculpted by forces of water and wind erosion (Liu, 1985). The plateau has a complex and diverse landscape, with a specific spatial distribution pattern of the modern landforms. The loess landforms were formed and developed on the basis of inheritance of the underlying paleotopography, the morphology and distribution of which profoundly affect the combination and spatial distribution of the modern landforms (Xiong et al., 2014a, b, c). The paleotopography underlying loess refers to the original terrain prior to loess deposition of the Quaternary period. Hence, a study of the paleotopography of underlying loess and its impact on the current loess landform is critical to understanding the formation mechanisms and the evolution of the landscape of the loess landforms.

In this paper, the underlying loess paleotopography, or the loess bedrock strata, is first taken into consideration for its controlling effect on the evolution of the landscape. On the basis of geologic maps, Remote Sensing (RS) images, DEMs, and loess thickness drilling points, we construct a DEM of the paleotopographic surface through intensive sampling of outcropping paleotopographic points in an area of severe soil erosion in the Loess Plateau. A terrain analysis method is then adopted to quantify the topographic differences and to reveal the loess-deposition process during the Quaternary period. The

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underlying terrain and a landscape evolution model is employed to virtualize the process of the loess landscape formation process.

II. Materials and Methods

A. Materials

DEM: SRTM (Shuttle Radar Topography Mission) with resolution 90 m was chosen as the basic DEM data source, because of its appropriate height precision and applicability to geomorphological mapping at macroscale (Zhan, 2008). Geologic map: an information source for outcropping points of bedrock in the loess area with scale 1:200,000, composed by the Institute of Geology and Geophysics of the Chinese Academy of Sciences. Remote sensing imagery was applied to positional correction within bedrock outcropping point mapping. Loess thickness distribution map (Liu, 1985): Tertiary red clay and early paleotopographic regions are designated on the geologic map. Hence, thickness distribution data of loess were used to provide further control for terrain simulation of the Tertiary surface.

B. Methods

1. Outcropping bedrock strata points detection

Coordinates and elevations for the bedrock outcrop strata points were collected based on the geologic maps, which assigned them a geologic age and rock type, such as Tertiary, Cretaceous, Jurassic (for geologic age), and basalt and limestone (for rock type). The method was implemented via the following steps. First, the bedrock outcropping points in channels or valleys with the same geologic age of Tertiary were determined based on the geologic maps. Second, an image-based positional correction of the bedrock points was done. Finally, an overall outcropping bedrock strata point dataset was constructed.

2. Underlying bedrock strata surface modelling

Based on the bedrock outcrop points, the DEM of underlying loess paleotopography in the experimental area was constructed via interpolation. Through a comparison of all the interpolation methods (Franke, 1982; Mitas and Mitasova, 1988), Spline was determined to be the most suitable method for this application because of its high accuracy, as well as its relatively low variation. Among all sampling points, 80 percent were prepared for interpolation; the rest (20 percent) were used for determining accuracy (the RMSE is 36.5 m, relative error is less than 12 percent) (Figure 1).

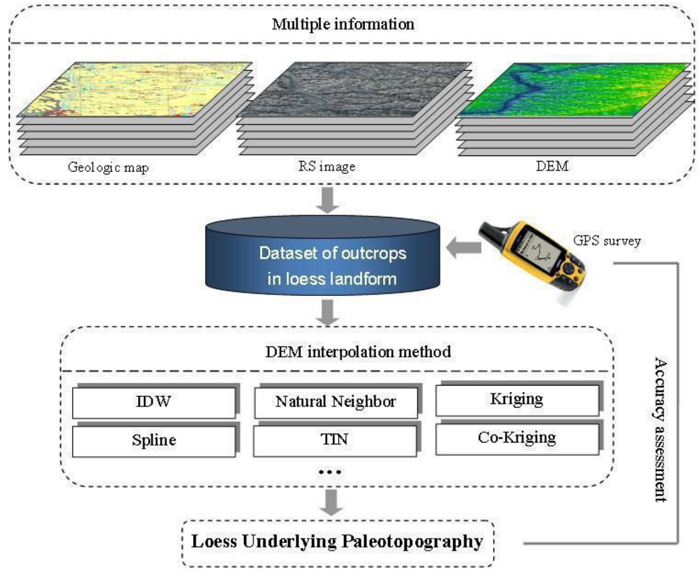

Figure 1. Virtualization and reconstruction of the underlying terrain

3. Loess landform evolution process evaluating

For both the modern terrain and the paleotopography, terrain profile characteristics and slope aspect were conducted. Terrain profile characteristics of the two surfaces was extracted from DEMs and evaluated based on of Lu et al. (2003). In the current study, the slope aspect (Burrough and McDonnell; 1998) was also calculated and a numerical statistical analysis was completed for eight different directions, N, NE, E, SE, S, SW, W and NW, which were classified to investigate the slope aspect changes.

III. Results

Significant differences were subjectively found in the spatial distribution between the modern DEM surface and the underlying paleotopographic surface. At the same time, the basic trend of these two terrains had some similarities. The differences and similarities reflect the landscape evolution as it developed from the pre-Quaternary to modern landscape. Terrain analysis of profile characteristics and slope aspect were used to test the differences and similarities, reveal the evolution of the landscape and its mechanism, and evaluate the underlying paleotopography for these two terrains. And then, the study integrates the virtualized underlying terrain into the landscape evolution model to further virtualize the process of loess landscape evolution.

A. Terrain profiles

Using a group of terrain profiles extracted from DEMs of the underlying and modern terrains, the spatial relationship and distribution pattern between them can be clearly illustrated

(Figure 2). R-squared values of both equations confirm the strong inheritance of the modern terrain from the underlying paleotopography.

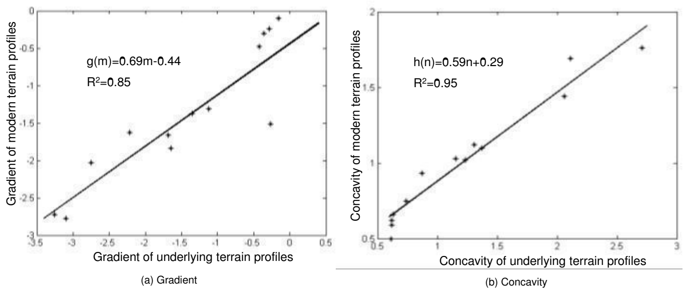

Figure 2. Linear correlations of modern terrain profiles and underlying terrain profiles

B. *Slope Aspect*

For this study, the slope aspect was derived for both the underlying terrain and the modern terrain, and a numerical statistical analysis was completed for eight different directions, N, NE, E, SE, S, SW, W, NW, which were classified to investigate the slope aspect changes (Figure 3). The frequency of N and NW appeared to increase significantly, while those of E and SE, by contrast, decreased significantly. In other words, a large quantity of E and SE aspects have been buried and reshaped into N and NW aspects. This result supports the hypothesis of an eolian origin for loess in China, namely, the difference of loess deposition in the windward slope (NW slope) and the leeward slope (SE slope). At the same time, other aspects also show a slight change from the underlying terrain to the modern terrain, which demonstrates the effect of water erosion mold force. The results demonstrate that the origin for loess in the study area was an interactive force that was dominated by an eolian origin, while water erosion mold force also contributed to reshaping the morphology of the loess landform during the loess-deposition process.

C. *Landscape evolution process*

With the virtualized underlying paleotopography and the landscape evolution model (Refice et al., 2012), the study further simulated the evolution process of loess landform. Figure 4(a, b, c, d, e, f) is the landscape evolution process under different condition. It shows that, under the controlling effect of origin terrain, the model virtualized different stages of the landform evolution process, and it appears great similarities with the true surface show in Figure 4(g, h, i), i.e. the loess hill, loess ridge and loess tableland landforms, which demonstrate the significance of the underlying origin terrain and the landscape

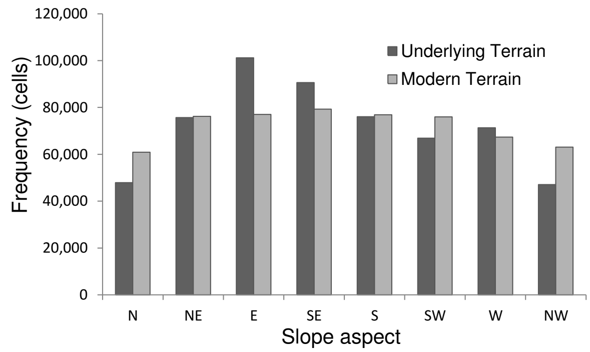

Figure 3. Comparison of modern and paleotopographic slope aspect distribution.

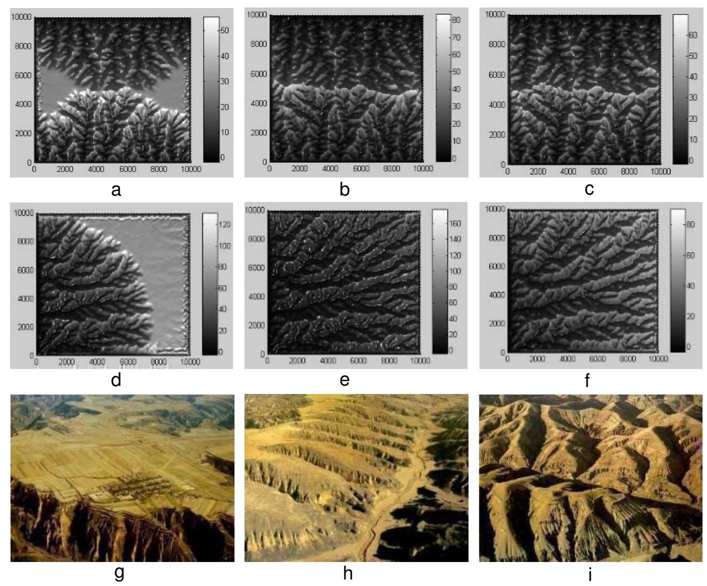

Figure 4. Evolution of a simulated surface. a, b, c, d, e and f are the landscape evolution processes under different conditions. g, h and i are loess hill, loess ridge and loess tableland landforms correspondingly.

IV. CONCLUSIONS

(1) Virtualization of the past or previous existing environment should be the content of VGEs. Multiple information reorganization and utilization could play a significant role in revealing the past, understanding now and predicting future. The virtualized and reconstructed underlying terrain profoundly controlled the formation of loess landform. The comparative analysis of paleotopography underlying loess and modern terrain was useful for revealing the geomorphological inheritance of loess landforms.

(2) The Ordos platform in China was once a smooth bedrock strata terrain in pre-Quaternary, but after more than 2 million years of loess deposition, loess accumulation, and loess transportation, the morphology of the Ordos platform has been reshaped. Moreover, the results suggest that the area for the aspects of N and NW increase significantly, while that for the aspects of E and SE decrease significantly, suggesting that the original slopes have been buried by the deposited loess dust, and after more than 2 million years of loess deposition, their original slope aspects have been reshaped into N and NW aspects to some extent. This result supports the hypothesis of an eolian origin for loess in China, namely, the difference of loess deposition in the windward slope (NW slope) and the leeward slope (SE slope).

(3) The results from the reconstruction of loess paleotopography can only be applied at a macro-level due to the limited sampling methods and density. The development of modern geophysical techniques would provide better conditions for the future study of loess landform evolution, investigating and modeling at even wider spatial scales.

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